STATISTICAL ANALYSIS OF THE EXPERIMENTAL DATA OBTAINED IN STUDYING OF WATER JET CLEANING

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ABSTRACT: This paper presents statistical analysis of experimental data obtained in the study of impact forces of water jets cleaning used for maintenance of sewers. The values of the impact forces were measured used own conception device. We established the process parameters, the number of levels and their values. Depending on these parameters was set a full factorial experimental design, completely randomized with seven blocks. Statistical analysis of experimental data consisted of: verifying the aleatory character of data, verifying the normality of the experimental data distribution, identifying data affected by aberrant errors.

KEY WORDS: cleaning water jet, statistical analysis, Romanowski test, Young test.

1 INTRODUCTION

An important role in an experimental research has statistical analysis of the data. Statistical analysis of experimental data obtained certifying that the values are real values of the process studied they are not affected by the system errors or measurement errors (Montgomery, 2013), (Țîțu & all, 2011).

Phenomena that occur in the cleaning water jets are complex. (Adler, 1979) describes mechanisms occurring at the impact of a jet with a surface. (Leach & all, 1966), (Leu & all, 1998) and (Guha & all, 2011) analysed pressure distribution along centerline of the water jet.

This paper aims statistical analysis of experimental data obtained in the study of the impact forces generated by high pressure water jets used for cleaning pipes.

In order to achieve an experiment raises two issues: 1) planning the experiment and 2) statistical analysis of the data.

Those two issues are interconnected between them, because statistical analysis depends on how planning and carrying out experiments.

To realize a statistical analysis in the design and analysis of a experiment it is necessary to be established with clarity from the beginning what to be studied, such as will be collected data, as well as how to analyse the data collected.

For this purpose it is recommended to follow a plan (a series of steps) to achieve an experimental research (Montogomery, 2013):

- recognition of and statement of the problem;
- selection of the response variable;
- choice of factors (process parameters), levels, and ranges;
- choice of experimental design;
- performing the experiment;
- statistical analysis of the data;
- conclusions and recommendations.

2 EXPERIMENTAL RESEARCH

We studied the impact forces generated at the contact between a water jet under pressure and a flat and rigid surface.

2.1 Setting the process parameters

After some preliminary experiments, it was established a number of three parameters involved in the process and the number of levels and their values (Medan, 2012).

These parameters are:

- nozzle diameter D;
- pressure of the jet at the outlet of the nozzle p;
- impact angle α between the jet and contact surface.

Table 1 presents the parameters and the chosen values.

Table 1. Values of the parameters used

Parameter	Values
D [mm]	1; 1.5; 2
p [bars]	100; 120; 140; 160; 180; 200
α [O]	60; 75; 90

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2.2 Choosing the type of experiment

Given the established process parameters and their values under discussion, it was determined that the type of experiment used to be a full factorial plan, randomization, with seven blocks.

As a result, it is necessary to carry out a number of 54 experiments, each experiment repeated 7 times, for a total of 378 measurements.

Of the 54 experiments, 18 are related to the angle $\alpha=90^{O}$.

If it is known the value of the impact force for $\alpha=90^{O}$, it can be calculated impact force for any angle α whose value is known (Medan, 2012), according to the equation:

$$F_{\alpha} = F_{90} \cdot \sin^2 \alpha \qquad (1)$$

where: F_{α} represent the impact force at angle α;

F_{90} represent the impact force at angle $\alpha=90^{O}$.

For the 18 experiments that correspond to angle $\alpha=90^{O}$ were performed 7 measurements for impact force.

For the other 36 experiments impact forces values were calculated corresponding to equation (1).

2.3 Perform the measurements

To perform the measurements has been designed and built a device to its own view (Medan, 2012).

In figure 1 is represented the principle diagram of the device for the measurement of the impact force of the water jet and a flat and rigid surface.

Main component parts of the device are: 1) high-pressure water hose, 2) support nozzle, 3) nozzle block, 4) nozzle, 5) water jet, 6) flat and rigid target plate, 7) collection path water, 8) scaled container for measurement of the flow of water jet, 9) piezoelectric sensor mounting, 10) piezoelectric sensor, 11) data acquisition Personal Daq/3000, 12) computer for the processing of data; 13) support plate, 14) acrylic tube, 15) rods for adjusting distance x.

From high pressure water hose (1) come water at a certain pressure p desired. At the outlet of nozzle is generated a water jet (5) that striking target plate (6), who it located at a certain distance x in front of the nozzle. The jet (5) generates an impact force at a time when he meets target plate (6). This force produces axial movement of target plate. This movement is converted into an electric signal by the piezoelectric sensor (10). Electrical signal is collected by data acquisition Personal Daq/3000 (11), which forward data to a computer (12) using DaqView soft processes data actually obtained.

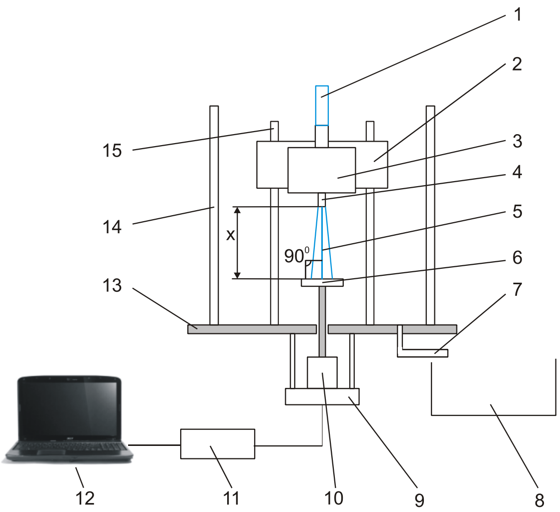

Figure 1. Diagram of the device for the measurement of the impact force of the water jet

Thus, was obtained values of impact forces, according to the experimental design.

Table 2 shows the electric voltage values obtained from measurements.

3 STATISTICAL ANALYSIS OF DATA

It was performed a statistical analysis of the data obtained in table 2.

Statistical analysis of experimental data consisted of: verifying the aleatory character of data, verifying the normality of the experimental data distribution, identifying data affected by aberrant errors.

3.1 Verifying the aleatory character of data

Verifying the aleatory character of data will be performed using the Young test. A string of experimental data is aleatory if the following condition is true:

$$v_{ci} < m < v_{cs} \qquad (2)$$

where:

- v_{ci} represent the critical inferior value;
- m represent the testing coefficient;
- v_{cs} represent the critical superior value.

The critical inferior value v_{ci} is calculated with:

$$v_{ci} = 0.491 + 0.081 \cdot n - 0.003 \cdot n^2 \qquad (3)$$

The critical superior value v_{cs} is calculated with formula:

$$v_{cs} = 3.317 - 1.057 \cdot e^{-8.919 \cdot n^{-0.941}} \qquad (4)$$

Table 2. Average electric voltage measured

No. exp.	D [mm]	P [bari]	α [^{O}]	Average electric voltage measured [mV]						
				Measurement number						
				1	2	3	4	5	6	7
1	1	100	90	450.79	438.18	429.19	422.38	425.61	433.89	445.65
2	1	120	90	530.21	531.39	518.80	526.81	514.25	517.65	506.97
3	1	140	90	609.22	600.46	598.07	590.11	596.77	598.73	592.89
4	1	160	90	756.96	769.66	772.66	746.57	738.39	736.72	757.35
5	1	180	90	827.20	837.76	863.41	835.83	836.56	854.58	836.82
6	1	200	90	974.72	958.74	1021.66	1015.28	1004.63	1003.44	993.21
7	1.5	100	90	944.05	932.78	923.74	938.31	950.76	970.07	945.10
8	1.5	120	90	1128.69	1111.66	1122.01	1142.91	1147.75	1131.76	1134.55
9	1.5	140	90	1305.38	1321.68	1329.22	1299.70	1322.95	1328.22	1354.56
10	1.5	160	90	1496.63	1509.29	1491.63	1509.36	1538.35	1519.02	1540.65
11	1.5	180	90	1718.06	1697.74	1683.22	1696.33	1714.21	1697.37	1705.34
12	1.5	200	90	1917.57	1901.38	1890.57	1899.63	1895.52	1900.13	1921.46
13	2	100	90	1572.99	1566.69	1566.47	1554.00	1560.06	1563.30	1559.67
14	2	120	90	1916.60	1916.47	1919.69	1925.58	1921.74	1923.33	1924.73
15	2	140	90	2238.02	2246.58	2236.49	2279.99	2290.63	2258.74	2263.75
16	2	160	90	2570.35	2582.92	2570.70	2582.16	2585.40	2588.02	2597.63
17	2	180	90	2914.73	2916.58	2913.83	2910.43	2918.98	2904.29	2901.82
18	2	200	90	3347.61	3335.63	3334.91	3350.29	3355.71	3338.39	3331.61

Table 3. Centralization of data to verify the aleatory character of data

Experiment no.	δ^2	s^2	v_{ci}	m	v_{cs}	Aleatory character
1	83.80	87.59	0.91	0.96	3.06	Yes
2	84.53	74.09	0.91	1.14	3.06	
3	207.82	18.26	0.87	2.28	3.11	
4	224.45	201.87	0.91	1.11	3.06	
5	361.82	157.94	0.91	2.29	3.06	
6	745.73	501.50	0.91	1.49	3.06	
7	110.27	78.87	0.87	1.4	3.11	
8	186.80	149.17	0.91	1.25	3.06	
9	194.12	127.09	0.87	1.53	3.11	
10	411.45	361.25	0.91	1.14	3.06	
11	243.66	221.23	0.91	1.10	3.06	
12	159.00	149.28	0.91	1.07	3.06	
13	42.56	40.97	0.91	1.04	3.06	
14	10.71	10.53	0.91	1.02	3.06	
15	537.01	427.40	0.91	1.26	3.06	
16	91.30	92.45	0.91	0.99	3.06	
17	52.92	47.58	0.91	1.11	3.06	
18	125.98	83.32	0.91	1.51	3.06	

The testing coefficient m is calculated with formula:

$$m = \frac{\delta^2}{s^2} \tag{5}$$

where: δ represent the average of successive differences and is calculated with formula:

$$\delta^2 = \frac{1}{n-1}\sum_{i=1}^{n-1}\left(x_{i+1} - x_i\right)^2 \tag{6}$$

s represent the dispersion of experimental data and is calculated with formula:

$$s^2 = \frac{1}{n-1}\sum_{i=1}^{n}\left(x_i - x_{ave}\right)^2 \tag{7}$$

where n represent the number of values of the array of experimental data. In this case is 7, and α represent confidence level. In this case α=0.95.

If the value of coefficient m satisfies the condition (2), then the array of experimental data meet the condition of aleatory character.

Table 3 shows a summary of the values obtained to verify the aleatory character of experimental data.

Conclusion. All experimental data sets verify the aleatory character.

3.2 Verifying the normality of the experimental data distribution

To verify the normality of the experimental data distribution will be used Shapiro-Wilk normality test. This test is used for data sets that do not exceed 50 values.

Calculation method is shown below.

It calculates the number of W defined by formula:

$$W = \frac{b^2}{\sum_{i=1}^{n}\left(x_i - x_{ave}\right)^2} \tag{8}$$

where b is a linear estimate of the standard deviation and is calculated based on the values of string data ordered. The denominator is the sum of squared deviations for the n measurements.

To determine the linear estimate of the standard deviation must divide the data into classes. Maximum number of classes k_{max} shall be determined on the basis of the number of values n of the string of data as follows: If n is an odd number then k_{max}=(n-1)/2.

For present strings data of this study k_{max}=3. In column values measurements arranges measurement values in ascending order.

Column x_I consists of first 3 measurement values in ascending order. Column x_{II} is made up of the last 3 measurements, in descending order.

From the tables (Tănăsescu, 1987) choose the coefficients a depending on the number of values taken into account and the number of groups k determined.

Summing column W_k·a is obtained b, the linear estimate of the standard deviation.

The value W obtained shall be related to the critical value W_{crt} of the tables (Tănăsescu, 1987).

Table 4 shows as an example the methodology for the calculation of the W number for the first experiment (table 2)

Conclusion. All the 18 sets of data verify the normality of the experimental data distribution.

3.3 Identifying data affected by aberrant errors

Identifying data affected by aberrant errors can be accomplished by applying the Romanowski test.

This test for identifying data affected by aberrant errors having applies for a number of up to 20 data.

The calculation formula for this test is given by the relation:

$$t = \frac{\left|x_e - x_{ave}\right|}{s\sqrt{\frac{n}{n-1}}} \tag{9}$$

where:

- x_e represent the value of a row, which will be tested;

Table 4. Shapiro-Wilk normality test, for first experiment

Experiment.	No. measure	Value of measure	k	x_I	x_{II}	W_k	a	W_k·a	AP
1	1	422.38	1	422.38	450.79	28.40	0.62	17.70	117.89
	2	425.61	2	425.61	438.18	12.57	0.30	3.81	58.18
	3	429.19	3	429.19	433.89	4.70	0.14	0.66	16.38
	4	433.89					b	22.17	0.37
	5	438.18							0.43
	6	445.63							24.42
	7	450.79							307.88
				W		W_{crt}		$\sum AP$	525.54
				0.94	>	0.803			

Table 5. Romanowski test for data sets

Experiment	x	Measured values	x_{ave}	s	t_{calc}	t_{crt}	Value remains Yes/No
$T_{1-100-90}$	$x1_{min}$	422.38	437.22	9.65	1.42	2.18	Yes
	$x7_{max}$	450.79	432.48	8.57	1.98		Yes
$T_{1-120-90}$	$x1_{min}$	506.97	523.18	7.20	2.08	2.18	Yes
	$x7_{max}$	514.25	521.97	9.31	0.77		Yes
$T_{1-140-90}$	$x1_{min}$	590.11	599.86	5.71	1.58	2.18	Yes
	$x7_{max}$	609.22	596.67	4.68	2.48		No
$T_{1-140-90}$ recalculated	$x1_{min}$	590.11	597.98	3.80	1.89	2.07	Yes
	$x6_{max}$	603.46	595.31	6.56	1.13		Yes
$T_{1-160-90}$	$x1_{min}$	736.72	756.93	13.12	1.43	2.18	Yes
	$x7_{max}$	772.66	750.94	12.70	1.58		Yes
$T_{1-180-90}$	$x1_{min}$	827.20	844.16	11.84	1.33	2.18	Yes
	$x7_{max}$	863.41	838.13	11.03	2.12		Yes
$T_{1-200-90}$	$x1_{min}$	958.74	1002.16	16.69	2.14	2.18	Yes
	$x7_{max}$	1021.66	991.67	21.16	1.31		Yes
$T_{1.5-100-90}$	$x1_{min}$	923.74	946.85	12.93	1.65	2.18	Yes
	$x7_{max}$	970.07	939.12	9.73	2.95		No
$T_{1.5-100-90}$ recalculated	$x1_{min}$	923.74	942.20	6.88	2.05	2.07	Yes
	$x6_{max}$	950.76	936.80	8.81	1.45		Yes
$T_{1.5-120-90}$	$x1_{min}$	1111.66	1134.61	9.42	2.16	2.18	Yes
	$x7_{max}$	1147.75	1128.60	10.78	1.65		Yes
$T_{1.5-140-90}$	$x1_{min}$	1299.70	1327.00	15.99	1.58	2.18	Yes
	$x7_{max}$	1354.56	1317.86	12.35	2.75		No
$T_{1.5-140-90}$ recalculated	$x1_{min}$	1299.70	1321.49	9.57	2.05	2.07	Yes
	$x6_{max}$	1329.22	1315.59	12.33	1.01		Yes
$T_{1.5-160-90}$	$x1_{min}$	1491.63	1518.88	17.50	1.44	2.18	Yes
	$x7_{max}$	1540.65	1510.71	16.73	1.66		Yes
$T_{1.5-180-90}$	$x1_{min}$	1683.22	1704.84	9.39	2.13	2.18	Yes
	$x7_{max}$	1718.06	1699.03	10.31	1.71		Yes
$T_{1.5-200-90}$	$x1_{min}$	1890.57	1905.95	10.76	1.32	2.18	Yes
	$x7_{max}$	1921.46	1900.80	9.12	2.10		Yes
$T_{2-100-90}$	$x1_{min}$	1554.00	1564.86	4.99	2.01	2.18	Yes
	$x7_{max}$	1572.99	1561.70	4.82	2.17		Yes
$T_{2-120-90}$	$x1_{min}$	1916.47	1921.92	3.36	1.51	2.18	Yes
	$x7_{max}$	1925.58	1921.92	3.45	1.38		Yes
$T_{2-140-90}$	$x1_{min}$	2236.49	2262.95	19.82	1.24	2.18	Yes
	$x7_{max}$	2290.63	2253.93	16.79	2.02		Yes
$T_{2-160-90}$	$x1_{min}$	2570.35	2584.47	8.76	1.49	2.18	Yes
	$x7_{max}$	2597.63	2579.93	7.56	2.17		Yes
$T_{2-180-90}$	$x1_{min}$	2901.82	2913.14	5.19	2.02	2.18	Yes
	$x7_{max}$	2918.98	2910.28	6.00	1.34		Yes
$T_{2-200-90}$	$x1_{min}$	3331.61	3343.75	8.64	1.30	2.18	Yes
	$x7_{max}$	3355.71	3339.74	7.50	1.97		Yes

- x_{ave} represent the average values in the series of data, but without the value tested x_e;

- s represent mean square deviation, but without the tested value x_e.

- n number of measurements.

This value is compared with the critical value t_{crt} (tabular value on the basis of the number of values in the series of data and the confidence interval (Tănăsescu, 1987).

If $t > t_{crt}$ then we have a value affected by aberrant error and eliminate the value in the string of data.

For an accuracy of 95%, the value $t_{crt}=2.18$ for a string of 7 values and $t_{crt}=2.07$ for a string of 6 values.

For ease of notation it was used a codification of experiments based on parameters. So $T_{2-200-90}$ reads as follows: experiment corresponding to parameters D=2mm, p=200bars and ∝=90^O. In Table 5 are centralized results obtained.

For $T_{1-140-90}$, $T_{1.5-100-90}$, $T_{1.5-140-90}$, has been identified as a value affected by aberrant errors. For these experiments was eliminated the value affected by aberrant errors and recovery the test for 6 measurements.

At the second check had not been data affected by aberrant errors.

Table 5 shows a summary of the Romanowski test to identifying the data affected by aberrant errors.

4 CONCLUDING REMARKS

In this paper we conducted a statistical analysis of experimental data of strings of values obtained from measurement the impact forces of water jets cleaning.

It has been used a device to perform the measurements of impact forces.

There were obtained 18 sets of values, each set containing 7 values.

Statistical analysis of experimental data consisted of:

1) Verifying the aleatory character of data. All experimental data sets verify the aleatory character.

2) Verifying the normality of the experimental data distribution. All the 18 sets of data verify the normality of the experimental data distribution.

3) Identifying data affected by aberrant errors. For the three sets of data, $T_{1-140-90}$, $T_{1.5-100-90}$, $T_{1.5-140-90}$, in the first verification have been identified an aberrant value. For these experiments was eliminated the value affected by aberrant errors and recovery the test for 6 measurements. At the second check had not been data affected by aberrant errors.

In conclusion, the next stage will work with datasets by 7 values, less the three data sets, $T_{1-140-90}$, $T_{1.5-100-90}$, $T_{1.5-140-90}$, for which will work with sets of six values.

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6 NOTATION

The following symbols are used in this paper:
D = nozzle diameter;
p = pressure of the jet at the outlet of the nozzle;
α = impact angle between the jet and contact surface;
Fα = impact force at angle α;
F_{90} = impact force at angle α=90^O;
v_{ci} = critical inferior value;
m = testing coefficient;
v_{cs} = critical superior value;
δ = average of successive differences and is calculated with formula;
s = dispersion of experimental data;
n = number of values of the array of experimental data;
b = linear estimate of the standard deviation;
k_{max} = maximum number of classes for Shapiro-Wilk normality test;
x_e = value of a row, which will be tested;
x_{ave} = average values in the series of data,;
s = mean square deviation.